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Detection of Radiofrequency Radiation-Induced Whole Body Heating Following Chemical Impairment of Thermoregulation

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16. ABSTRACT

Heating by radiofrequency (RF) radiation at high intensities can cause biological changes by whole-body hyperthermia or by altered thermal gradients within the body. However, there have been reports of effects at low intensities of RF radiation without evidence of increased temperature. Over the years, there has been considerable controversy concerning the potential for RF radiation to cause biological effects in experimental animals in the absence of detectable increases in body or tissue temperature. In many instances, the effects produced by RF radiation have been attributed to direct interactions (athermal or field-specific effects) unrelated to any detectable temperature change in the biological specimen.

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Detection of Radiofrequency Radiation - Induced Whole Body Heating Following Chemical Impairment of Thermoregulation

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I. INTRODUCTION

Heating by radiofrequency (RF) radiation at high intensities can cause biological changes by whole-body hyperthermia or by altered thermal gradients within the body [Johnson and Guy, 1972]. However, there have been reports of effects at low intensities of RF radiation without evidence of increased temperature [Baranski and Czerski, 1976]. Over the years, there has been considerable controversy concerning the potential for RF radiation to cause biological effects in experimental animals in the absence of detectable increases in body or tissue temperature. In many instances, the effects produced by RF radiation have been attributed to direct interactions

(i.e., athermal or field-specific effects) unrelated to any detectable temperature change in the biological specimen.

Using behavioral and physiological thermoregulatory techniques, Stern et al., (1979) and Adair and Adams (1980) recently demonstrated that animals could detect subtle heating by RF radiation during cold stress at a power density below 10 mW/cm^2. In earlier work (1977), Putthoff et al. (1977) showed increases in the core temperature of rats made hypothermic with cortisone and exposed to RF radiation. These results indicate that animals made hypothermic by drugs or subjected to cold stress may be sensitive models for the detection of subtle RF-induced heating.

To further examine the hypothermia model in two rodent species lipopolysaccharide (LPS) or endotoxin from Gram-negative bacteria was used to induce hypothermia in rats (Feldberg and Saxena, 1975) and 5-hydroxytryptamine (5-HT) was used to produce hypothermia in mice (Dooley and Quock, 1976). Impairment of thermoregulation by endotoxin in the rat and 5-HT in the mouse allowed us to detect subtle whole body heating by RF radiation at a power density (1 mW/cm^2) heretofore considered to be non-temperature increasing.

II. METHODS

The methods employed are those reported previously

(Smialowicz et al., 1980, 1981). Unless stated otherwise, experimentally naive young adult rats and mice were used once and then killed after several days of observation. Rats were injected intravenously with a single dose of Salmonella typhimuriun LPS and mice intraperitoneally with a single dose of 5-HT creatine sulfate complex. Control animals were injected with an equal volume of pyrogen-free saline.

Immediately following injection, individual rats were placed in vented acrylic restrainers and mice placed in vented polycarbonate boxes. Four such animals were placed each in one of four positions of a diamond-shaped array in an environmentally controlled exposure chamber which was positioned beneath a 10-db-gain pyramidal horn antenna in the far field. The animals were exposed to RF radiation of fields generated by a Varian Model PPS-2.5 AS industrial heating unit at a frequency of 2450 MHz in a continuous-wave mode (Smialowicz et al., 1980). Species-, strain- and age-matched LPS- or 5-HT-injected animals were positioned in a similar array in a sham-irradiation chamber. A common environmental control for the RF exposure and sham-irradiation system permitted regulation of the temperature and humidity, unless stated otherwise, at 22 ± 0.5°C and 50 ± 10%, with an air flow of 4.3 m^3/min.

Prior to injection of LPS or 5-HT and immediately following exposure to RF radiation the colonic temperatures of the animals were measured with a Model 520 YSI (Yellow

Springs Instrument Co., Yellow Springs, Ohio) thermister probe inserted 2.5 cm beyond the anal sphincter in mice and with a Model 401 thermister probe inserted 8.0 cm beyond the anal sphincter in rats. Temperatures were read to an accuracy of 0.1°C from a YSI Model 46 telethermometer.

III. RESULTS

A. Detection of RF Heating in Rats

The time-dependent temperature response of rats injected with 40 µg LPS and maintained at an ambient temperature of 22°C and relative humidity of 50% is shown in Figure 1. Under these conditions the maximal hypothermic response occurred approximately 90 minutes following injection. Colonic temperatures returned to normal after 3-4 hours. Forty µg (approximately 100 µg/kg) of LPS per rat is well below the LD_{50} of 1.6 mg/kg (Smialowicz et al., 1980). Since the nadir of the hypothermic response of rats to LPS occurred at 90 minutes post-injection, subsequent experiments with RF radiation were conducted for this length of time.

Figure 1

In a power density series (1, 5, and 10 mW/cm^2) at 2450 MHz, increasing body temperature of LPS-injected rats was observed to be related to increasing power density (Figure 2). At each power density, the mean colonic temperature was significantly greater ($P < 0.05$, Dunnett's t-test) than that

Figure 2

of LPS-injected, sham irradiated rats. The specific absorption rate (SAR) for rats in this study was approximately 0.2 W/kg per 1 mW/cm^2. This SAR value was obtained by twin-well calorimetry reported by Kinn (1977) and Smialowicz et al. (1979a).

Rats injected with pyrogen-free saline and exposed for 90 minutes at an average power density of 5 mW/cm^2 did not show a significant increase in colonic temperature compared with saline-injected, sham-irradiated controls (Figure 2). A statistically significant difference ($P < 0.05$, Student's t-test) was observed in the colonic temperature of saline-injected rats exposed at 10 mW/cm^2).

In another experiment, two groups of rats were acclimated to handling procedures two weeks prior to LPS injection and RF radiation exposure. Figure 2 shows that when these rats were irradiated with 2450 MHz RF radiation at 0.5 mW/cm^2 their mean colonic temperature, while not significantly different, was 0.6°C higher than sham-irradiated LPS-injected rats. These results suggest that rats appropriately acclimated to handling and then made hypothermic with LPS may serve as an even more sensitive model for detection of RF-induced heating than naive rats.

Figure 3

The effect that ambient temperature alone has on the magnitude of endotoxin-induced hypothermia is shown in Figure

3. The colonic temperature of hypothermic rats was ambient temperature dependent. Only when the ambient temperature exceeded 30°C was the colonic temperature of LPS-induced hypothermic rats greater than saline-injected rats held at 22°C.

These results indicate that small doses of thermalizing energy from low-intensity (SAR $\leq$ 1 W/kg) RF radiation are detectable as significant increases in core temperature. In normal rats (saline-injected), the thermalization by RF radiation at these low intensities must be compensated by an increase in the rate of heat loss. This compensation by heat loss is exceeded when rats were irradiated at 10 mW/cm^2, as evidenced by a significant increase in the core temperature of saline-injected rats exposed at 10 mW/cm^2 (Figure 2).

B. Detection of RF Heating in Mice

Figure 4

The time-dependent hypothermic response of BALB/C mice to 5-HT at 22°C and 50% humidity is shown in Figure 4. The nadir of body temperature of mice treated with 5-HT occurred approximately 15 min following injection. Colonic temperatures returned to normal within 90 minutes. Mice were exposed to RF radiation during the first 15 min following 5-HT injection.

Table 1

Table 1 shows the colonic temperature response of 5-HT injected mice exposed to 2450 MHz RF radiation at several

power densities. Two strains of mice were used, male CBA/J and female BALB/C mice. Mice were maintained in an environment at 22°C, 50% relative humidity with an air flow of 4.3m³/min during irradiation. Significant ($P < 0.05$, Student's t-test) increases in the colonic temperature of 5-HT treated BALB/C mice were observed at 10, 5 and 1 mW/cm^2 compared with 5-HT treated sham-irradiated mice. CBA/J mice irradiated at 10 and 5 mW/cm^2 also showed significantly ($P < 0.05$) greater core temperatures compared with their sham-irradiated controls. At 1 mW/cm^2, 5-HT treated CBA/J mice had higher core temperatures than shams, although not significantly. Saline-injected BALB/C or CBA/J mice irradiated at 10 mW/cm^2 showed no significant increase in core temperature. The SAR for mice in this study was approximately 0.7 W/kg at 1 mW/cm^2. This value was obtained by twin-well calorimetry (Smialowicz et al., 1979b).

Figure 5

The effect that ambient temperature has on the hypothermic response of 5-HT-treated CBA/J mice is shown in Figure 5. Core temperature increased linearly with increasing ambient temperature. Even at an ambient temperature of 34°C the hypothermic effect of 5-HT was still evident.

IV DISCUSSION

These results demonstrate that once undetectable RF heating can be detected in rats made hypothermic by LPS and mice made hypothermic by 5-HT at a power density heretofore

considered to be non-temperature increasing. Significantly greater core temperatures in hypothermic rats and mice were meausred at SARs of 0.2 W/kg and 0.7 W/kg respectively. With acclimation of test animals to handling procedures the detection of temperature increases in hypothermic rats was increased. The response to RF radiation was then dependent on the power density at which the animals were exposed. No significant increase in the body temperature of rats or mice injected with saline and irradiated at 5 mW/cm^2 was observed compared with sham-irradiated saline-injected animals. It appears that heating of saline-injected animals by RF radiation can be compensated by thermoregulatory mechanisms since no increase in colonic temperature occurred following irradiation at 5 mW/cm^2. In the LPS injected rats and 5-HT injected mice, normal thermoregulatory mechanisms were impaired by these agents and RF heating led to core temperature increases. Heat from the ambient environment also caused increased core temperatures in hypothermic animals.

A re-evaluation of the RF radiation bioeffects literature is indicated by these studies. More prudent assessment of claims for "nonthermal" (i.e., absence of measurable elevation of tissue or body temperature) RF-induced effects are needed, with consideration of the thermogenic potential of RF radiation as a cause for such changes.

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DISCLAIMER

This report has been reviewed by the Office of Research and Development, EPA, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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LEGENDS

Figure 1: Time-dependent temperature response of rats held at 22°C to endotoxin, (Smialowicz et al., 1980).

Figure 2: The effect of 90 minutes radiofrequency irradiation on endotoxin-induced hypothermia in rats, (Smialowicz et al., 1980).

Figure 3: The effect of ambient temperature on colonic temperature of rats 90 minutes after injection of endotoxin, (Smialowicz et al., 1980).

Figure 4: Time-dependent temperature response of BALB/C mice held at 22°C to 5-hydroxytryptamine, (Smialowicz et al., 1981).

Figure 5: The effect of ambient temperature on colonic temperature of CBA/J mice 15 minutes after injection of 5-hydroxytryptamine, (Smialowicz et al., 1981).

Table 1: Colonic temperature response of 5-hydroxytryptamine-injected mice to 2450 MHz radiofrequency radiation, (Smialowicz et al., 1981).

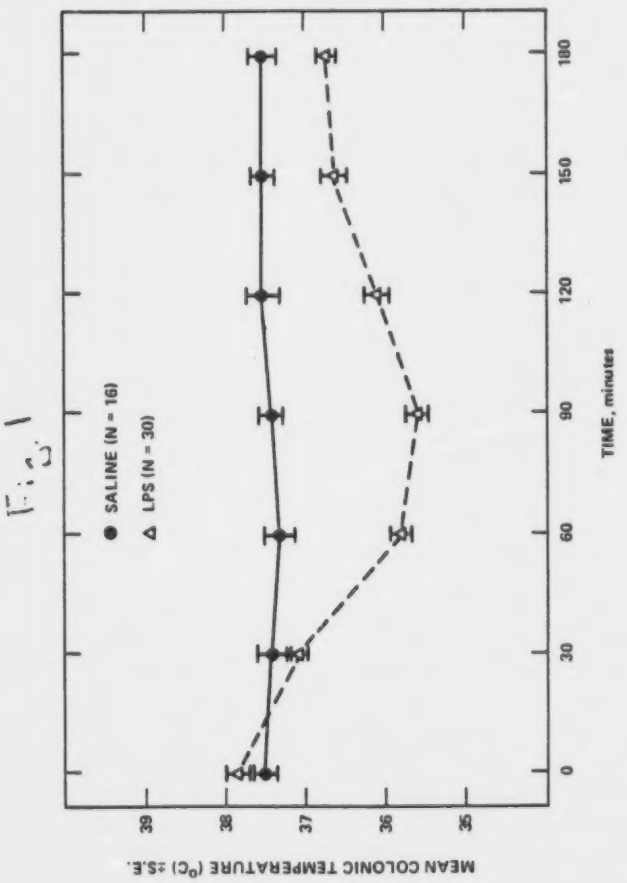

MEAN COLONIC TEMPERATURE (°C) ±S.E.
39
38
37
36
35
0
30
60
90
120
150
180
TIME, minutes
● SALINE (N = 16)
△ LPS (N = 30)

Fig. 1

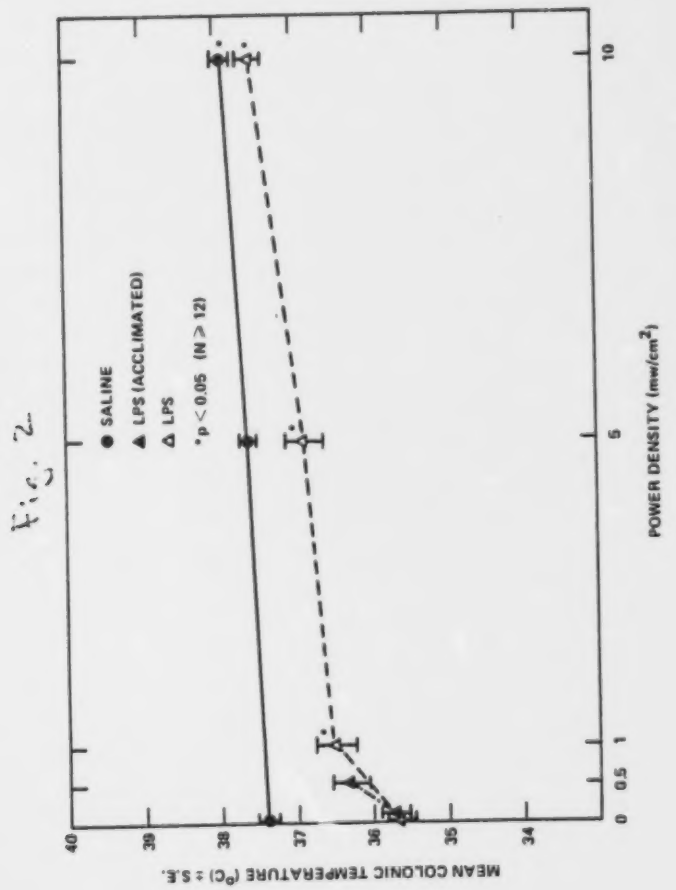

MEAN COLONIC TEMPERATURE (°C) ± S.E.
40
39
38
37
36
35
34
0
0.5
1
5
10
POWER DENSITY (mw/cm²)
● SALINE
▲ LPS (ACCLIMATED)
△ LPS
*p < 0.05 (N ≥ 12)

Fig. 2

Fig. 3

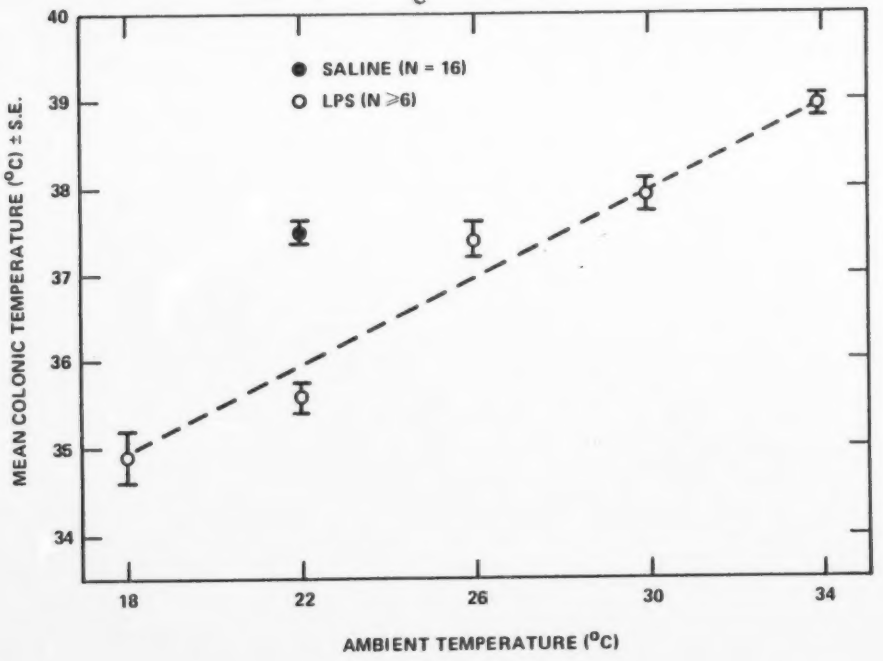

SALINE (N = 16)
LPS (N ≥6)
MEAN COLONIC TEMPERATURE (°C) ± S.E.
40
39
38
37
36
35
34
18
22
26
30
34
AMBIENT TEMPERATURE (°C)

Fig. 4

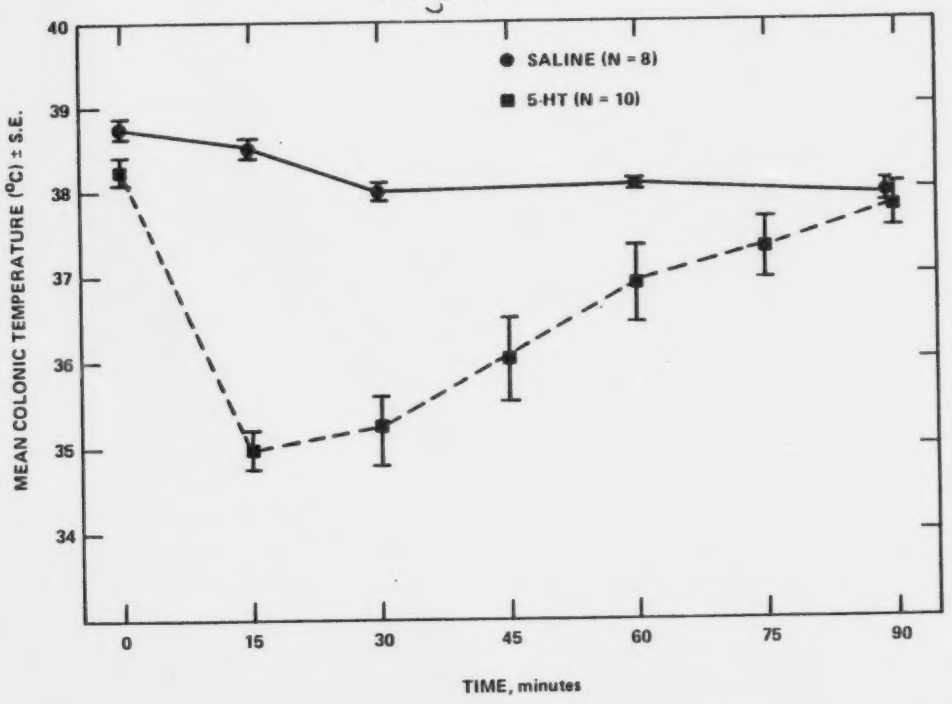
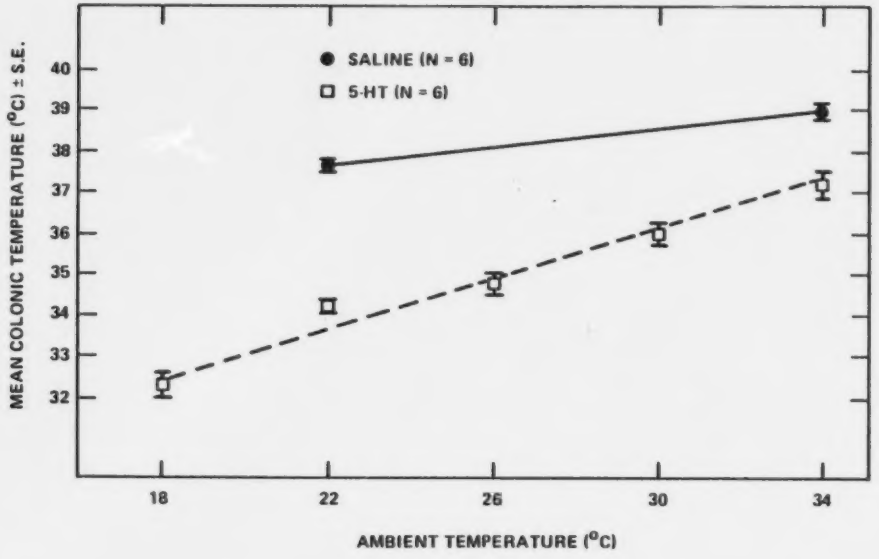

SALINE (N = 8)
5-HT (N = 10)
MEAN COLONIC TEMPERATURE (°C) ± S.E.
40
39
38
37
36
35
34
0
15
30
45
60
75
90
TIME, minutes

Fig. 5


SALINE (N = 6)
5-HT (N = 6)
MEAN COLONIC TEMPERATURE (°C) ± S.E.
40
39
38
37
36
35
34
33
32
18
22
26
30
34
AMBIENT TEMPERATURE (°C)

9/

Table 1. EFFECT OF 2450 MHz RADIOFREQUENCY RADIATION ON COLONIC TEMPERATURE OF 5-HYDROXYTRYPTAMINE-INDUCED HYPOTHERMIC MICE

STRAIN	TREATMENT	POWER DENSITY (mw/cm^2)	MEAN COLONIC TEMPERATURE (^oC) ± SE		P
			SHAM[a]	IRRADIATED	
BALB/C	5-HT	1	34.3 ± 0.1	34.8 ± 0.1	< 0.05
		5	34.8 ± 0.1	35.7 ± 0.1	< 0.01
		10	34.5 ± 0.2	36.5 ± 0.2	< 0.01
	SALINE	10	38.5 ± 0.1	38.7 ± 0.1	N.S.
CBA/J	5-HT	0.5	34.2 ± 0.3	34.7 ± 0.2	N.S.
		1	34.5 ± 0.2	35.0 ± 0.2	0.051
		5	34.4 ± 0.2	35.6 ± 0.2	< 0.01
		10	34.7 ± 0.2	36.3 ± 0.3	< 0.01
	SALINE	10	37.6 ± 0.2	37.7 ± 0.1	N.S.

[a]EIGHT TO TWELVE MICE AT EACH POWER DENSITY.